

$|V_{cb}|$ and $|V_{cs}|$ measurement @ future lepton colliders

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@ECFA WG1 Meeting, 18/04/2024

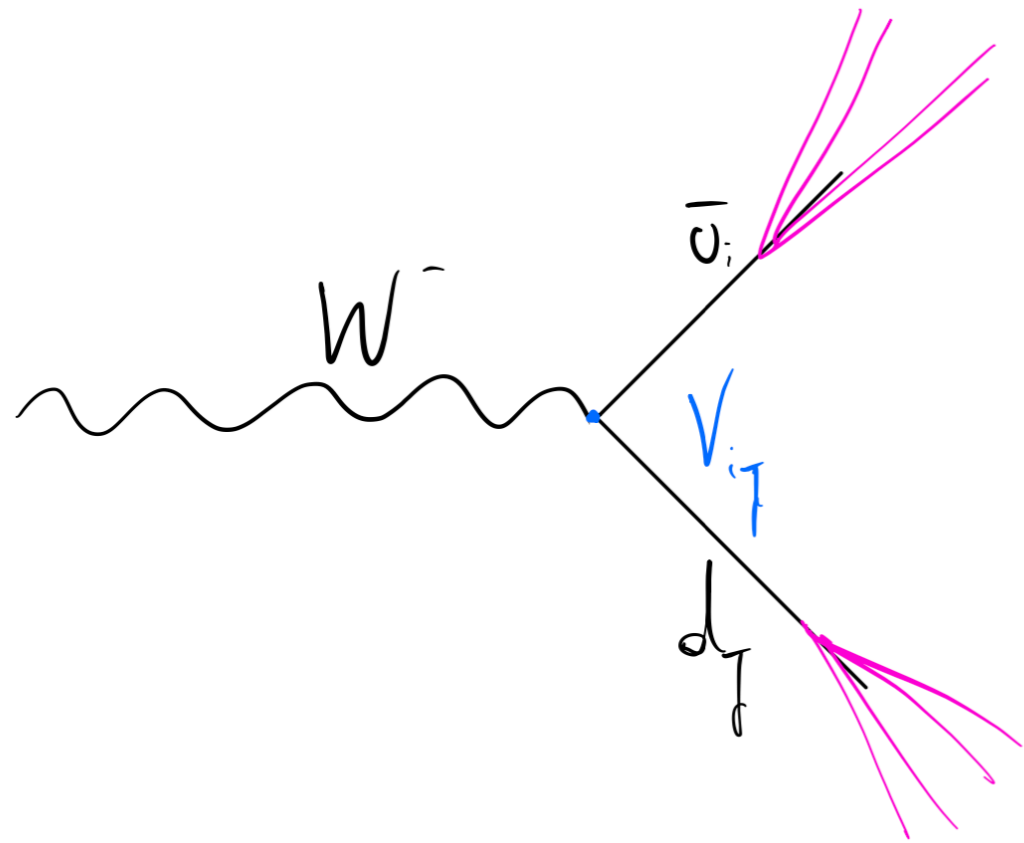
with

D. Marzocca, S. Monteil, M. H. Schune, M. Selvaggi, M. Szewc



Istituto Nazionale di Fisica Nucleare
SEZIONE DI FIRENZE

Produce **on-shell W bosons**



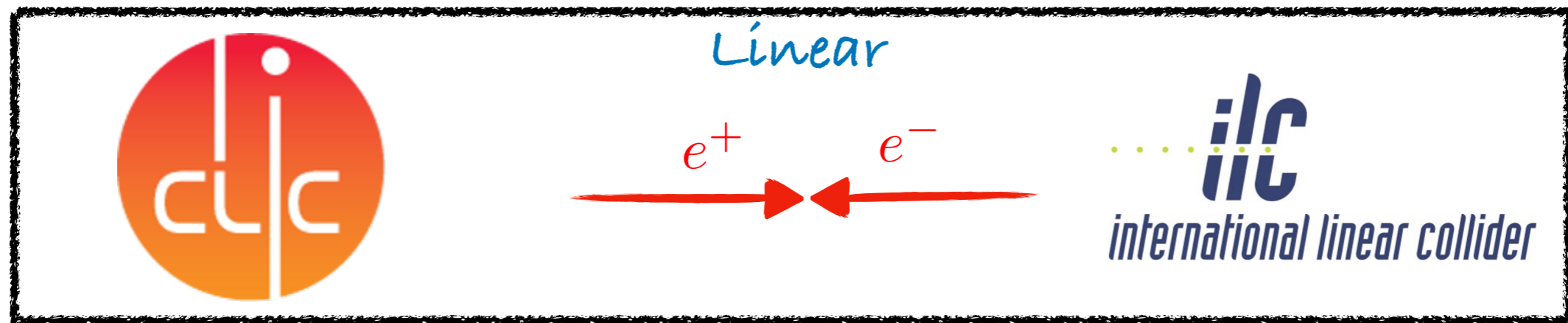
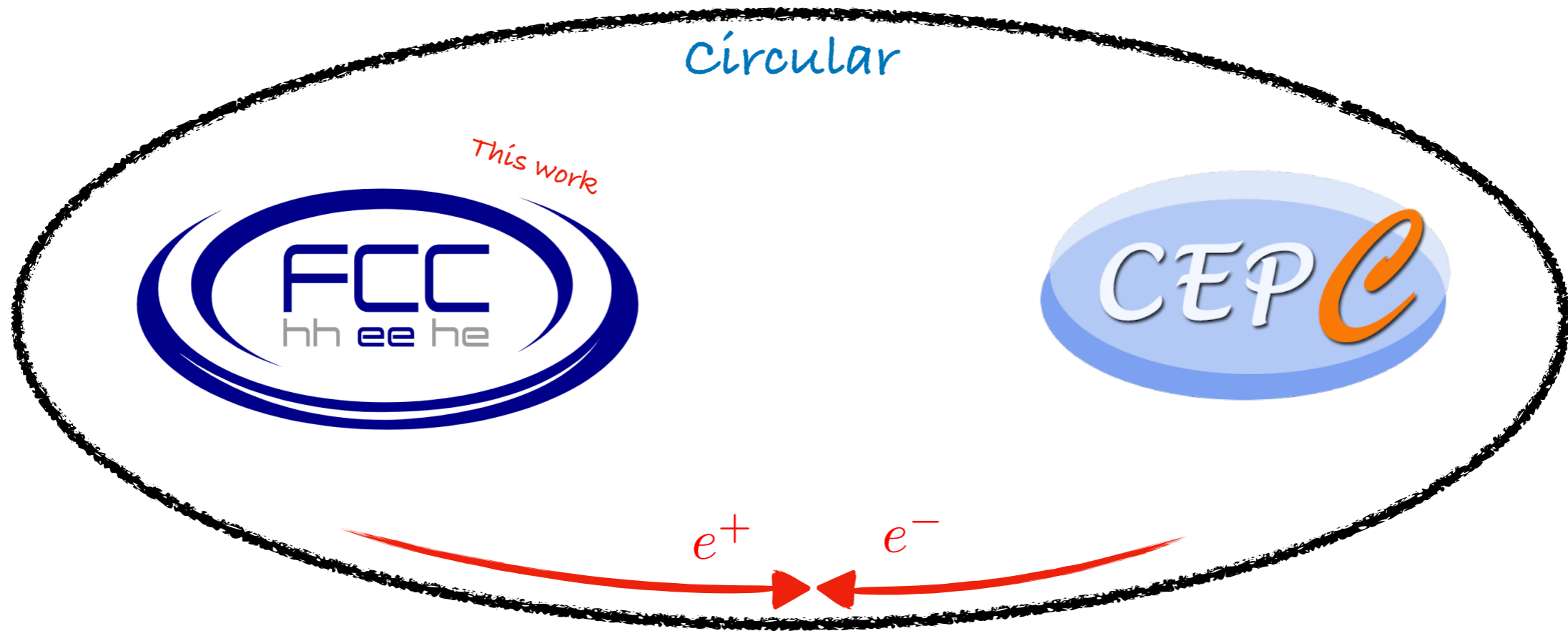
With **large statistics** and **low background**

$$\begin{pmatrix} |V_{ud}| & |V_{us}| & |V_{ub}| \\ |V_{cd}| & |V_{cs}| & |V_{cb}| \\ |V_{td}| & |V_{ts}| & |V_{tb}| \end{pmatrix}$$

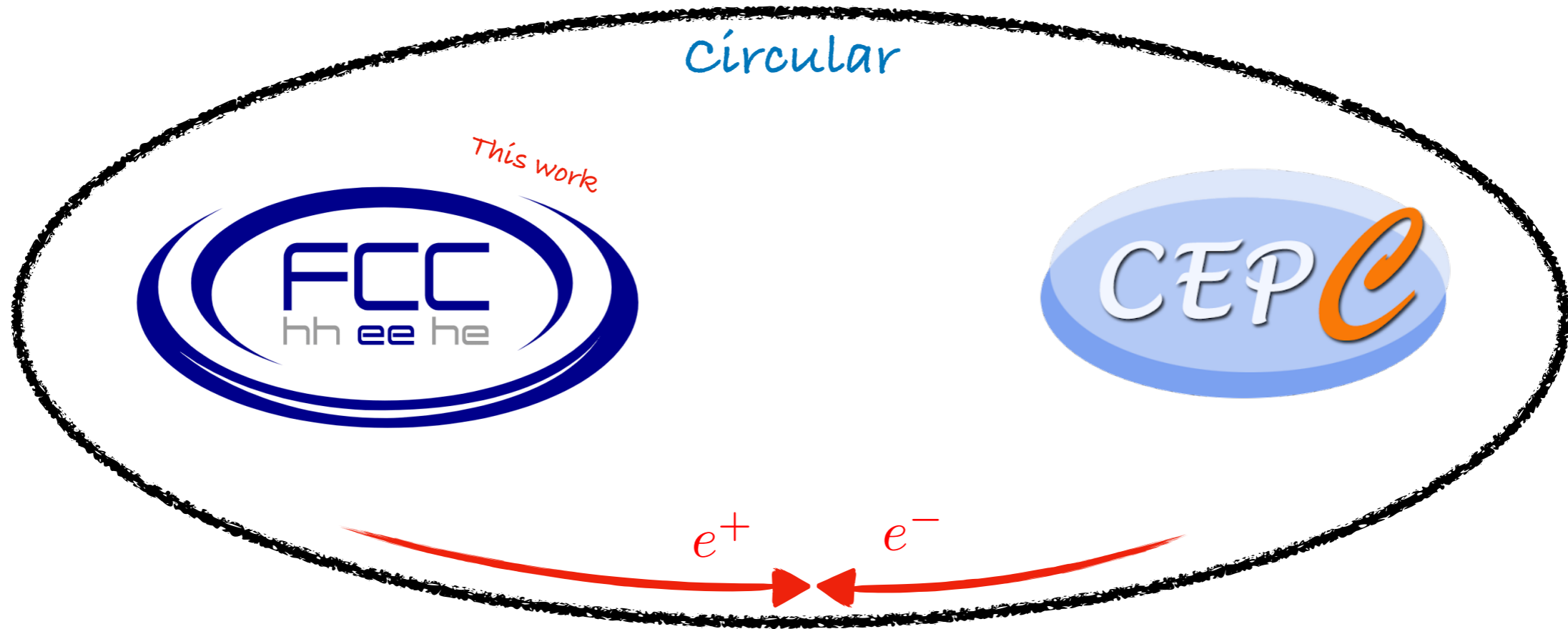
Apply **flavor taggers**

Count events

The landscape of future lepton colliders



The landscape of future lepton colliders



$$Z \text{ pole} \rightarrow N_Z \sim 5 \times 10^{12}$$

$$Zh \text{ thr.} \rightarrow N_h \sim 6 \times 10^5$$

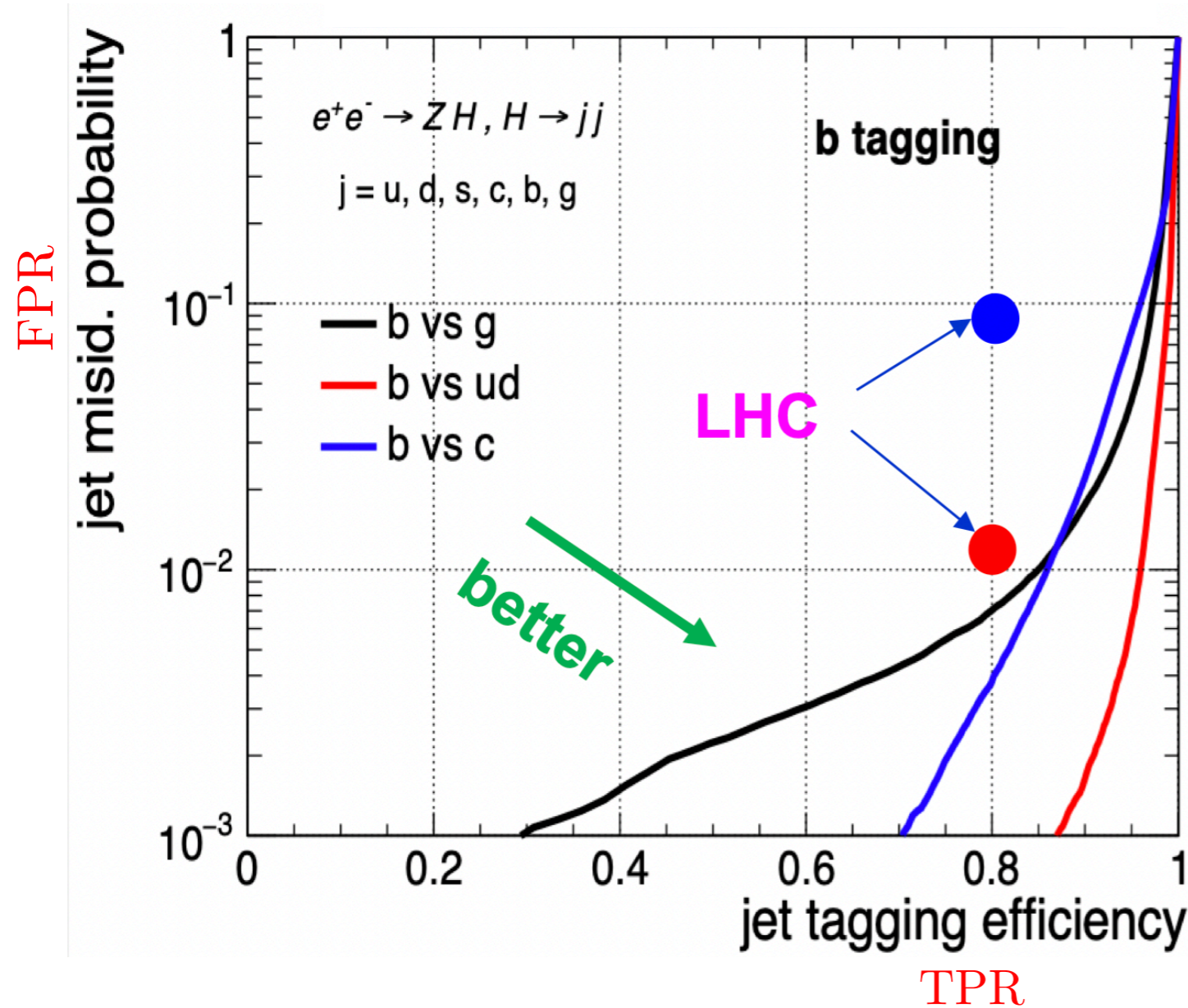
$$WW \text{ thr.} \rightarrow N_W \sim 6 \times 10^8$$

$$t\bar{t} \text{ thr.} \rightarrow N_t \sim 10^6$$

Jet flavor taggers

Tools to classify flavor of jets from input data

ParticleNet: 1902.08570
 Jet-Flavor tagging at FCC-ee: 2210.10322



$$\beta = \{b, s, c, u, d, g\}$$

$$\epsilon_{\beta}^b = \{0.8, 0.0001, 0.003, 0.0005, 0.0005, 0.007\}$$

Currently $\mathcal{O}(\text{few})\%$ syst. on ϵ_{β}^q

ATLAS: 1907.05120
 CMS: 1712.07158

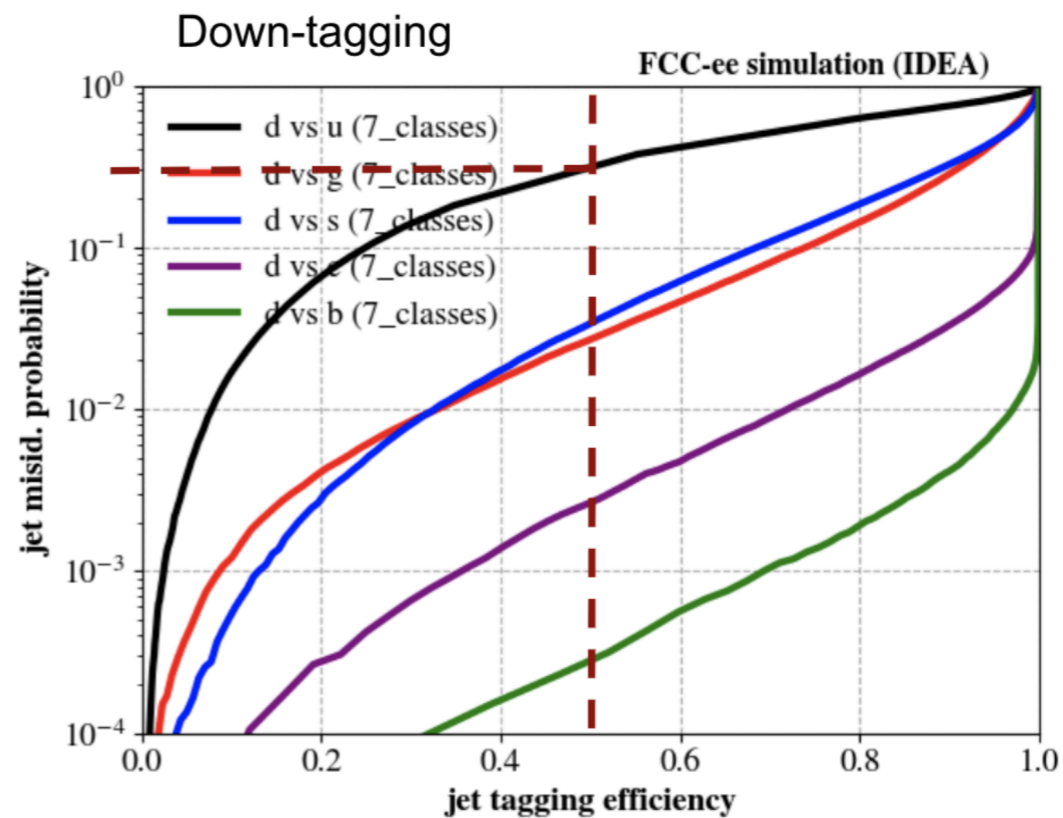
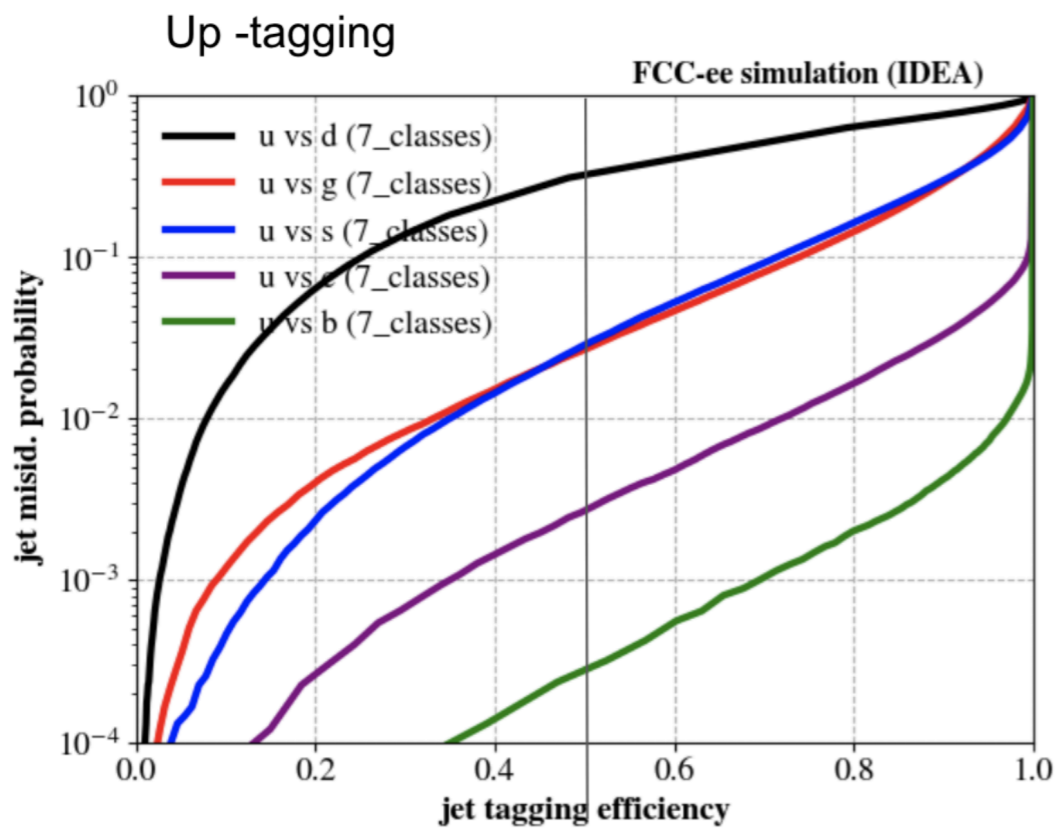
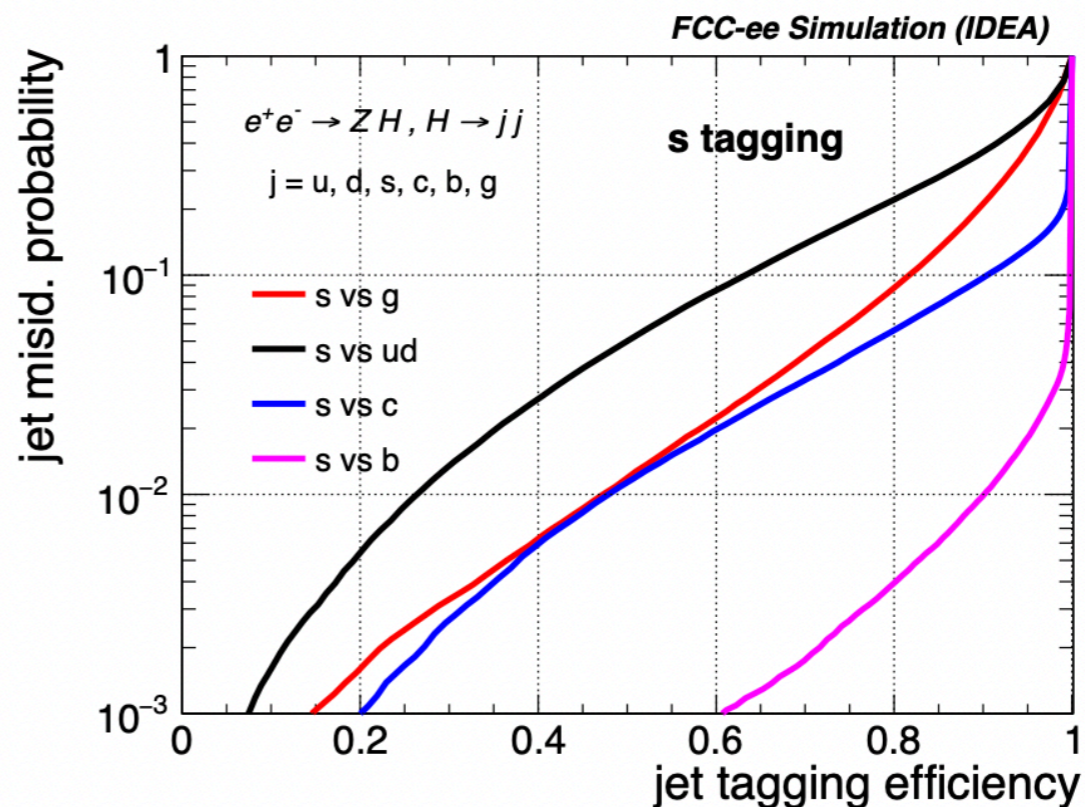
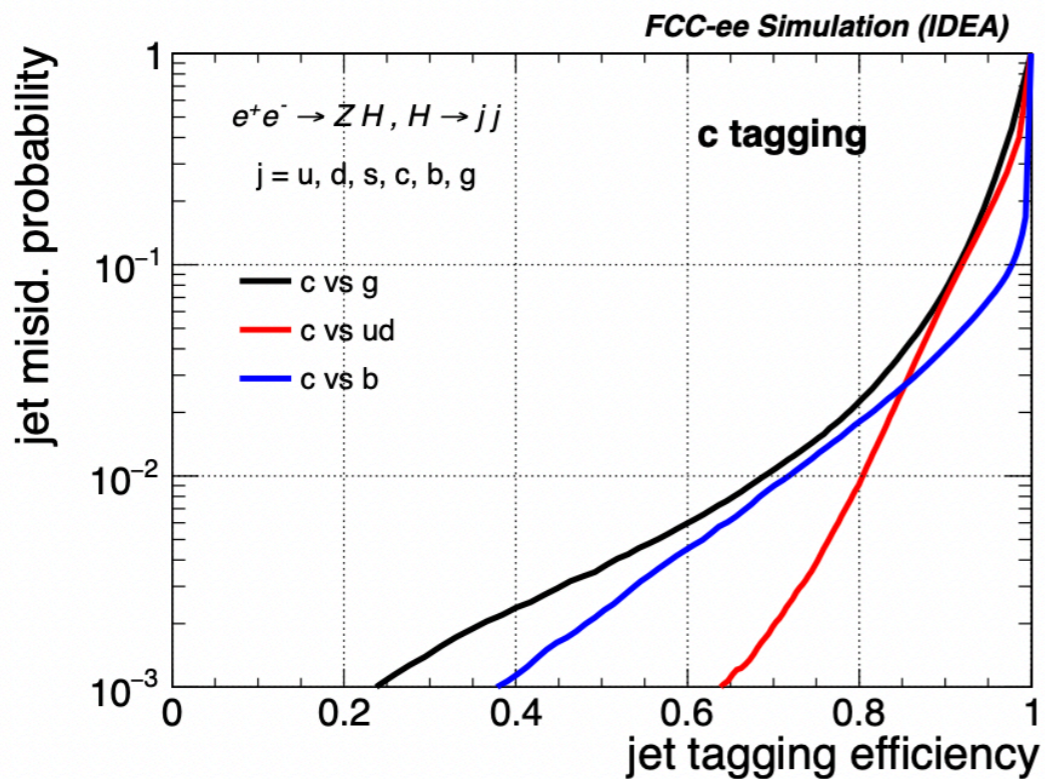
Calibration at Z-pole

Could go to 0.1%

Bedeschi, Gouskos, Selvaggi: 2202.03285
 Gouskos' talk at "FCC Physics Workshop" (indico.cern.ch/event/1176398/)

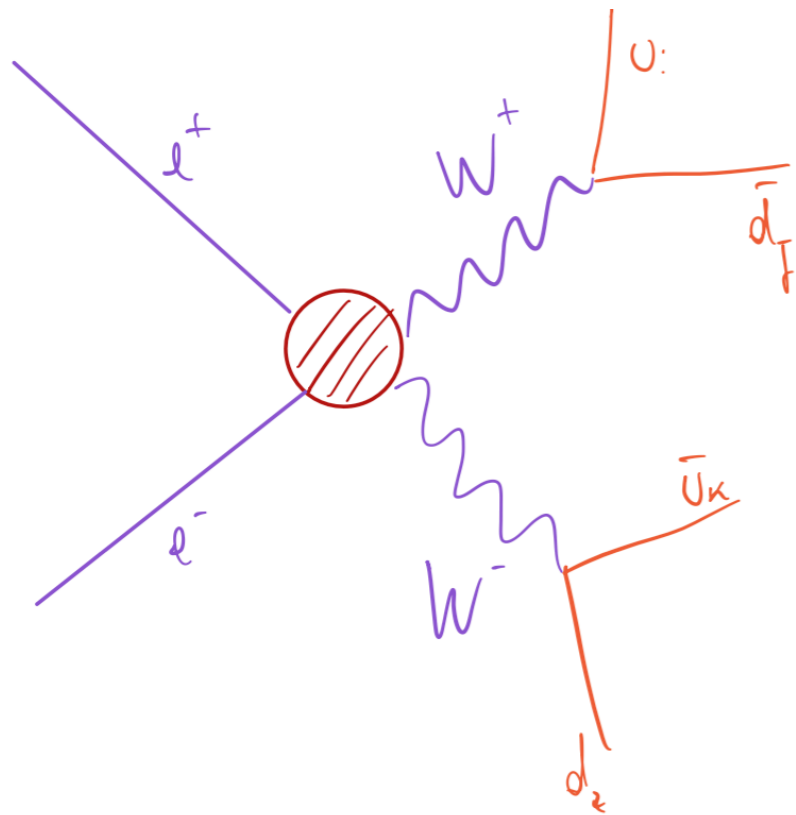
M. Selvaggi's talk at 7th FCC Workshop
 (<https://indico.cern.ch/event/1307378/>)

Jet flavor taggers



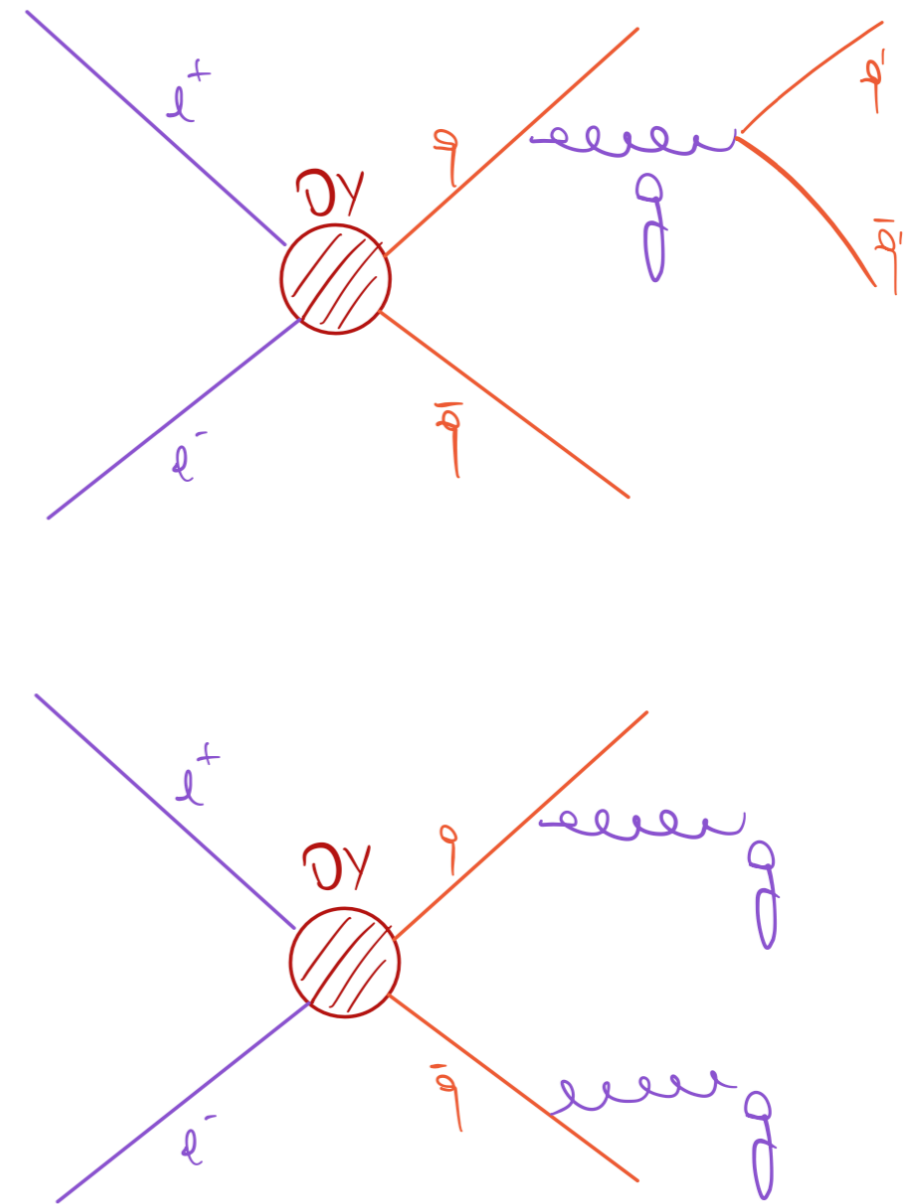
Signal

$$e^+e^- \rightarrow W^+W^- \rightarrow 4j$$



Backgrounds (Drell-Yan)

$$e^+e^- \rightarrow 4j, 2j2g$$

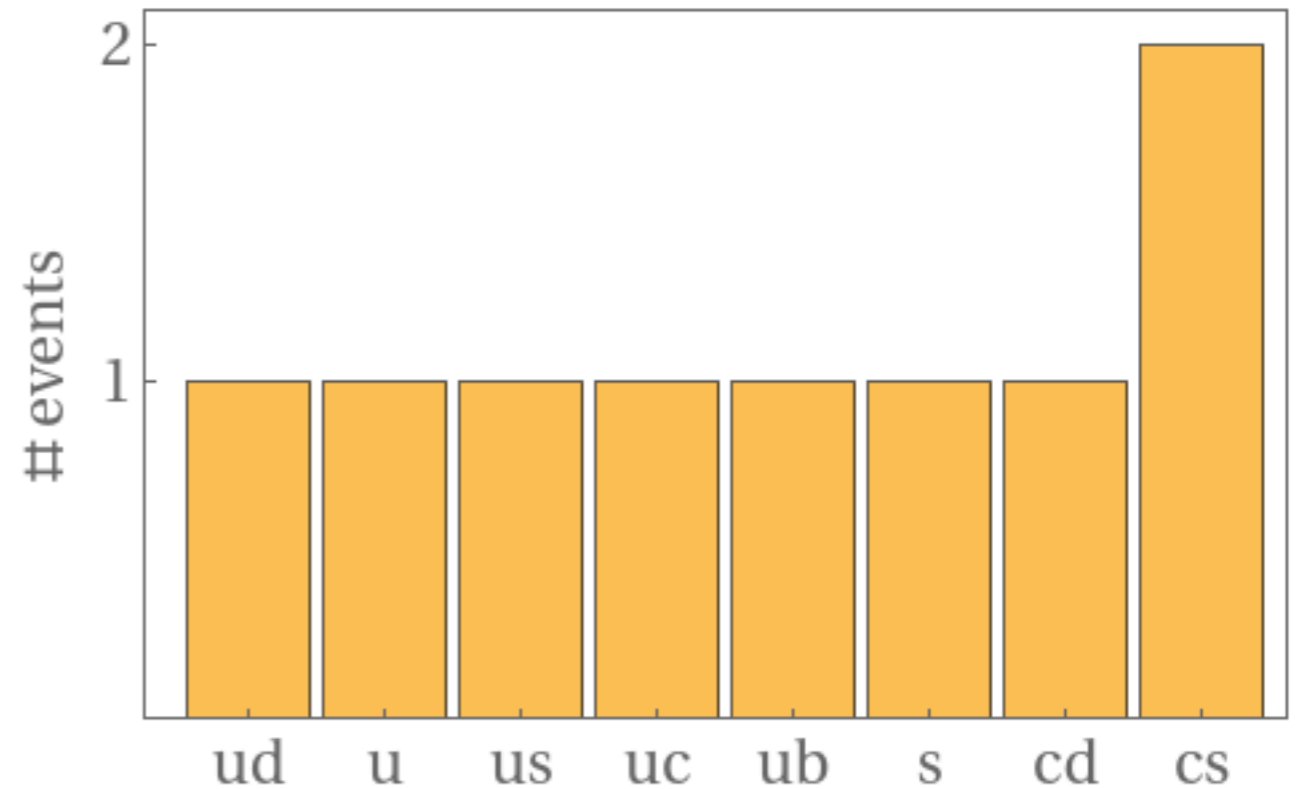
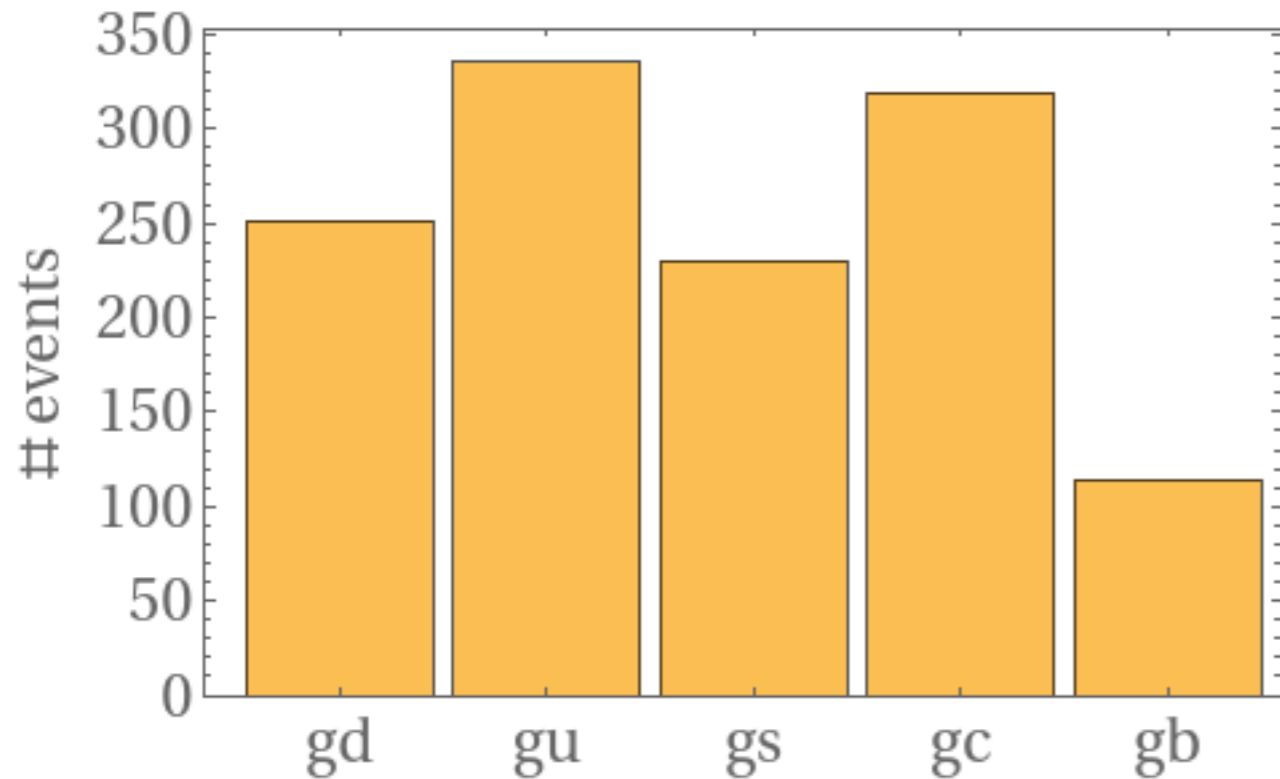


10^6 events with MadGraph (parton level only)

Selection: at least one couple of invariant masses such that

$$(m_{ij}, m_{kz}) \supset (m_W \pm \sigma_W, m_W \pm \sigma_W)$$

$\sim 10^3$ events pass



Probabilistic model

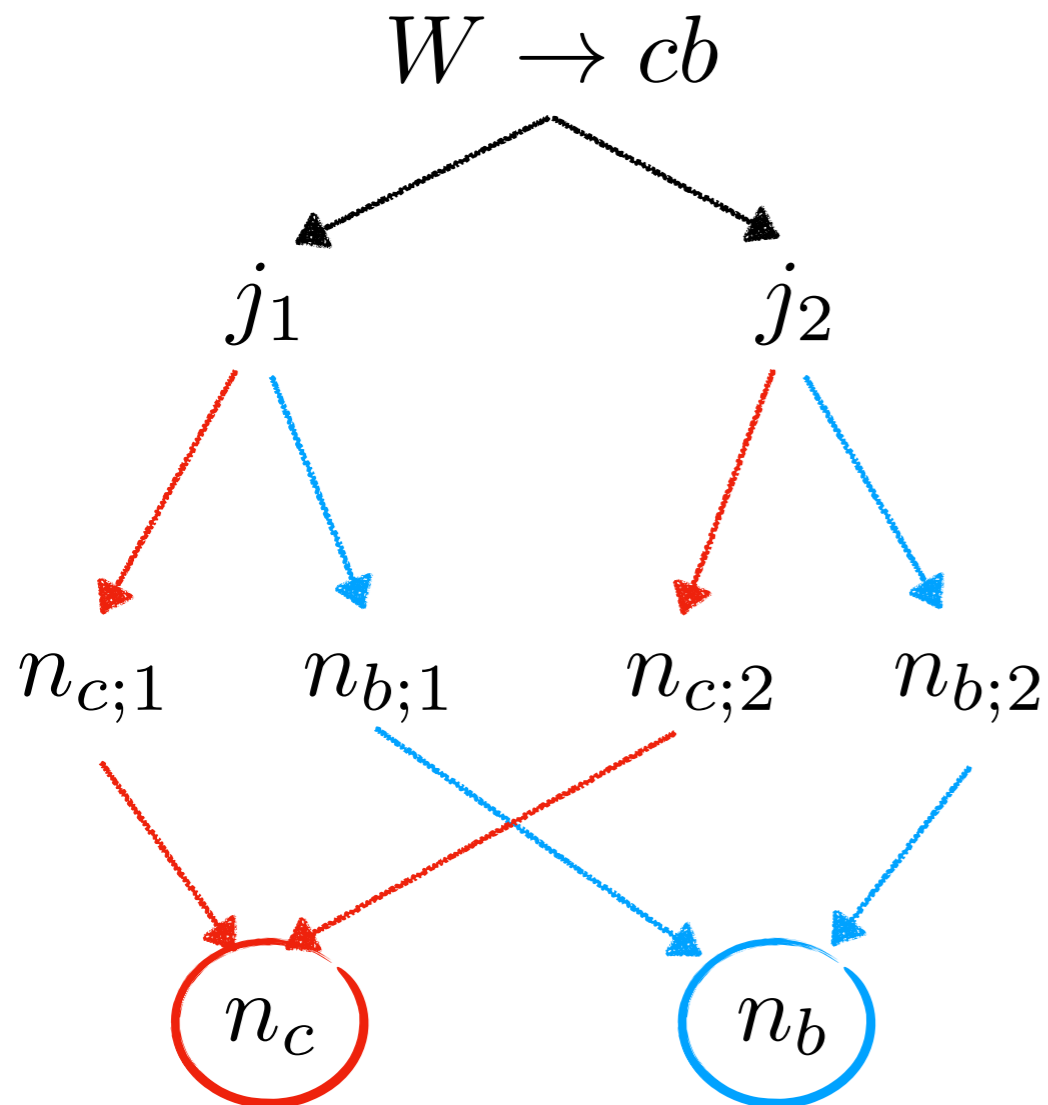
ATLAS: 2201.11428

CMS: 2004.12181

Faroughy, Kamenik, Szewc, Zupan: 2209.01222

Distribute events into tag bins

$$(n_c, n_b) = \{(0, 0), (0, 1), (1, 0), (2, 0), (0, 2), (1, 1)\}$$



Expected number of events per channel

$$\bar{N}_f = \mathcal{B}(W \rightarrow f) N_W \mathcal{A}$$



Expected number of events per tag bin

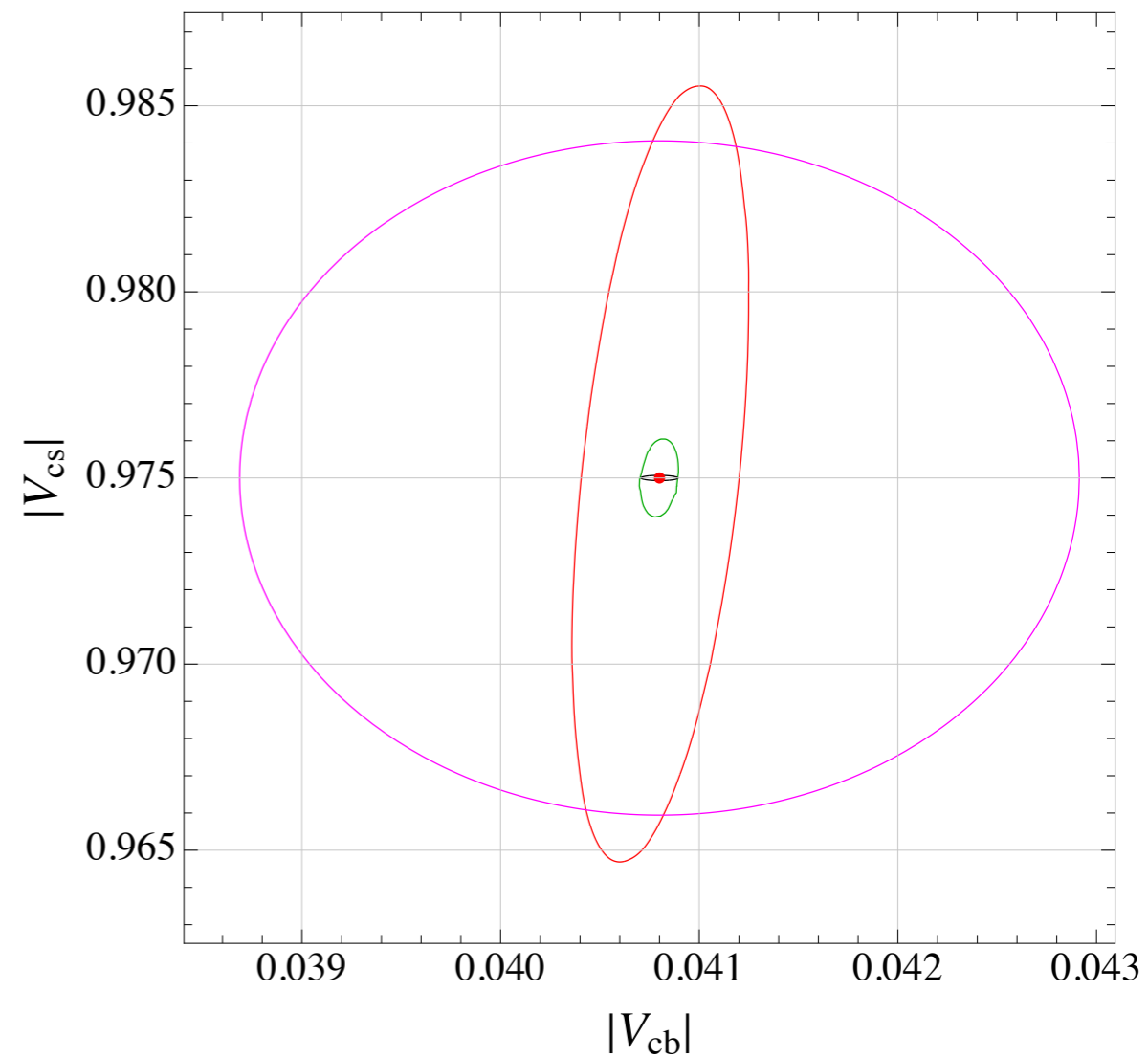
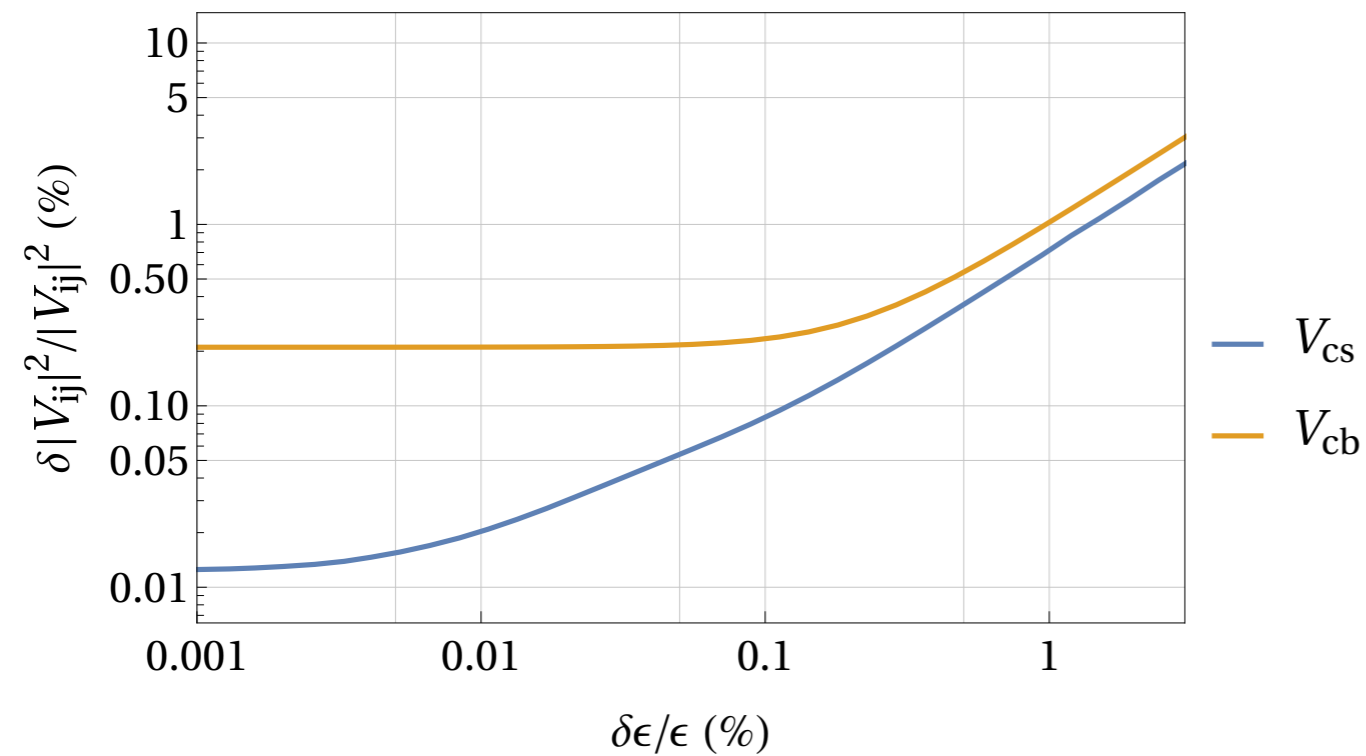
$$\bar{N}_{(n_c, n_b)} = \sum_f p(n_c, n_b | f, \nu) \bar{N}_f(\nu)$$

Nuisance parameters $\nu = \{N_W, \mathcal{A}, \epsilon_\beta^q, \dots\}$

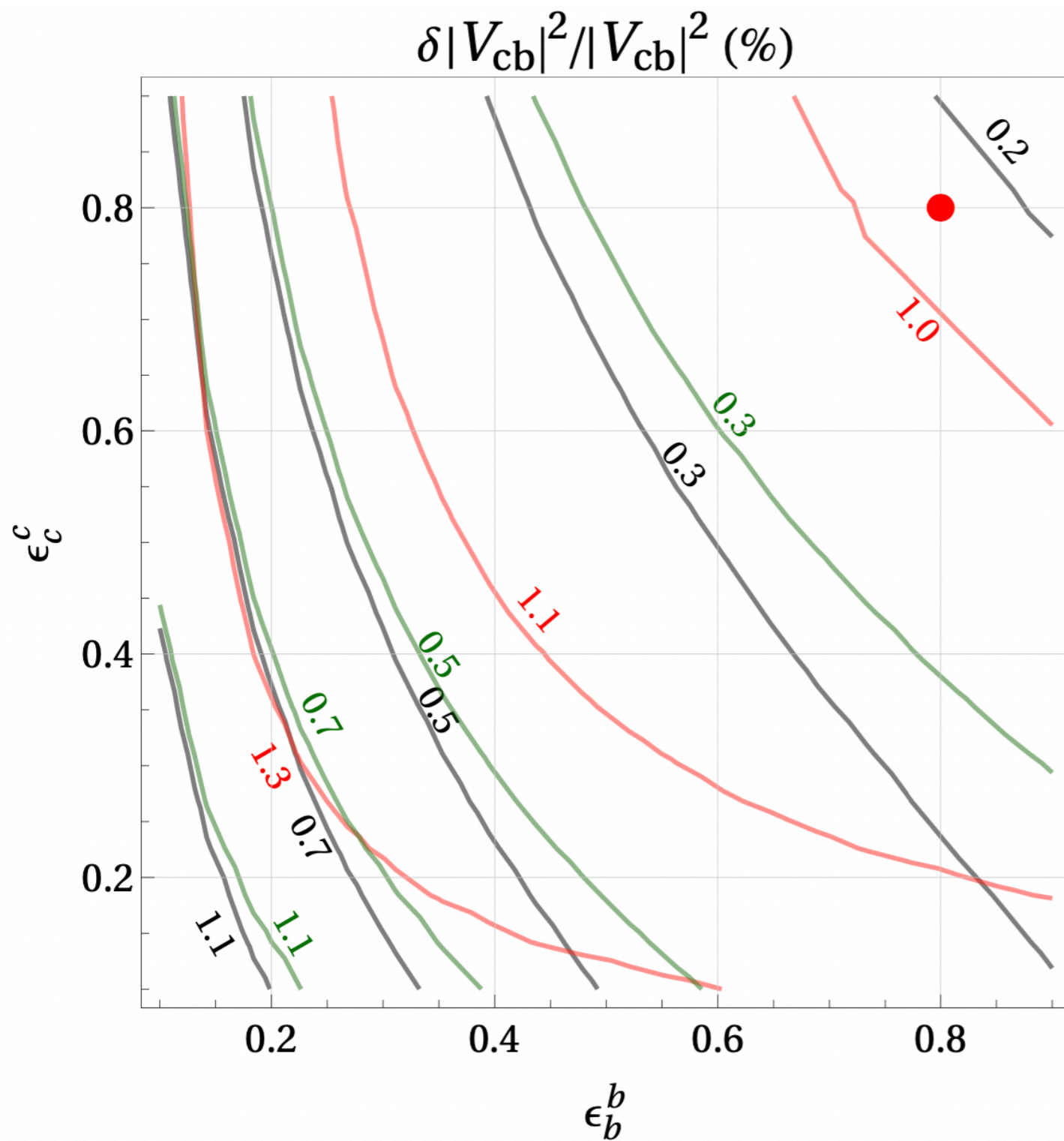
Results 1: fixed Working Point

Project % sensitivity on $|V_{ij}|$

$ V_{ij} $	Current	FCC-ee (0.1%)	FCC-ee (1%)
$ V_{cs} $	0.975 ± 0.006 (0.6%)	0.086	0.72
$ V_{cb} $	$(40.8 \pm 1.4) \times 10^{-3}$ (3.4%)	0.23	1.0



Results 2: scan parameters



Reminder

$\epsilon_\beta^q \equiv q$ -tagger probability to tag β -jet

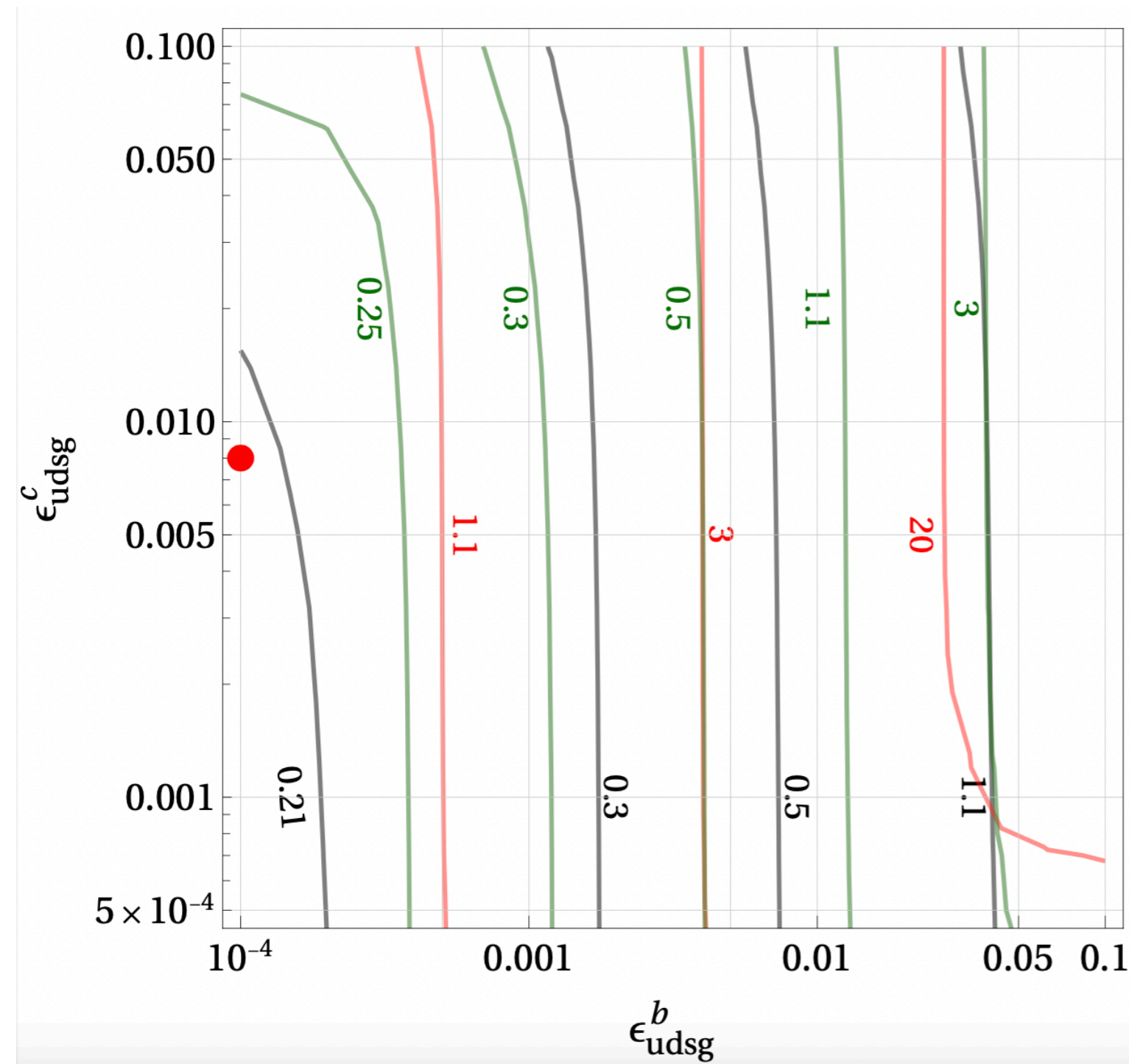
● FCC-ee Working Point

– No systematics

– 0.1% systematics

– 1% systematics

Results 2: scan parameters



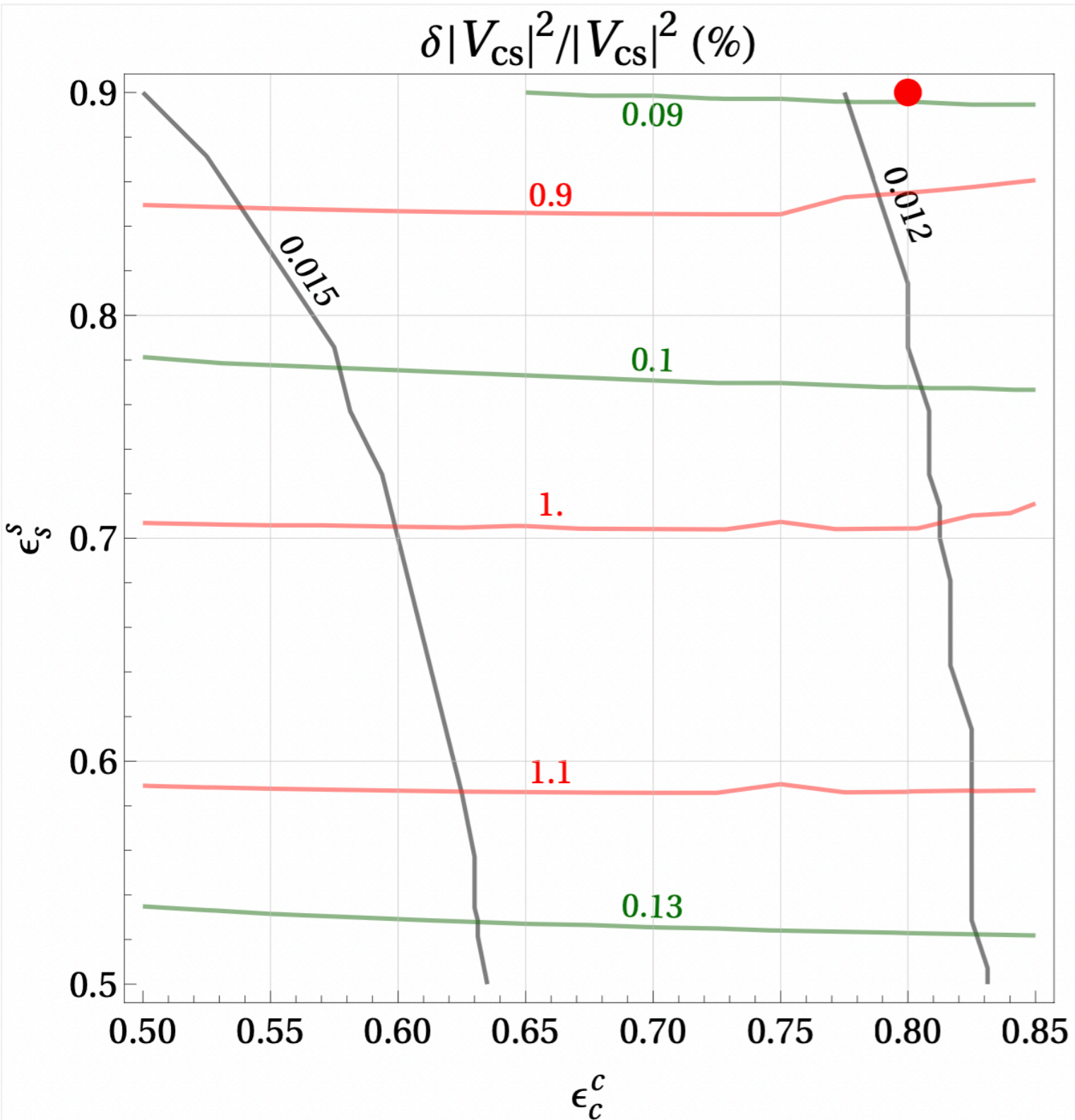
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- No systematics
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- 1% systematics

Final precision dictated by $b \rightarrow$ light-jet mistags

Results 2: scan parameters



Reminder

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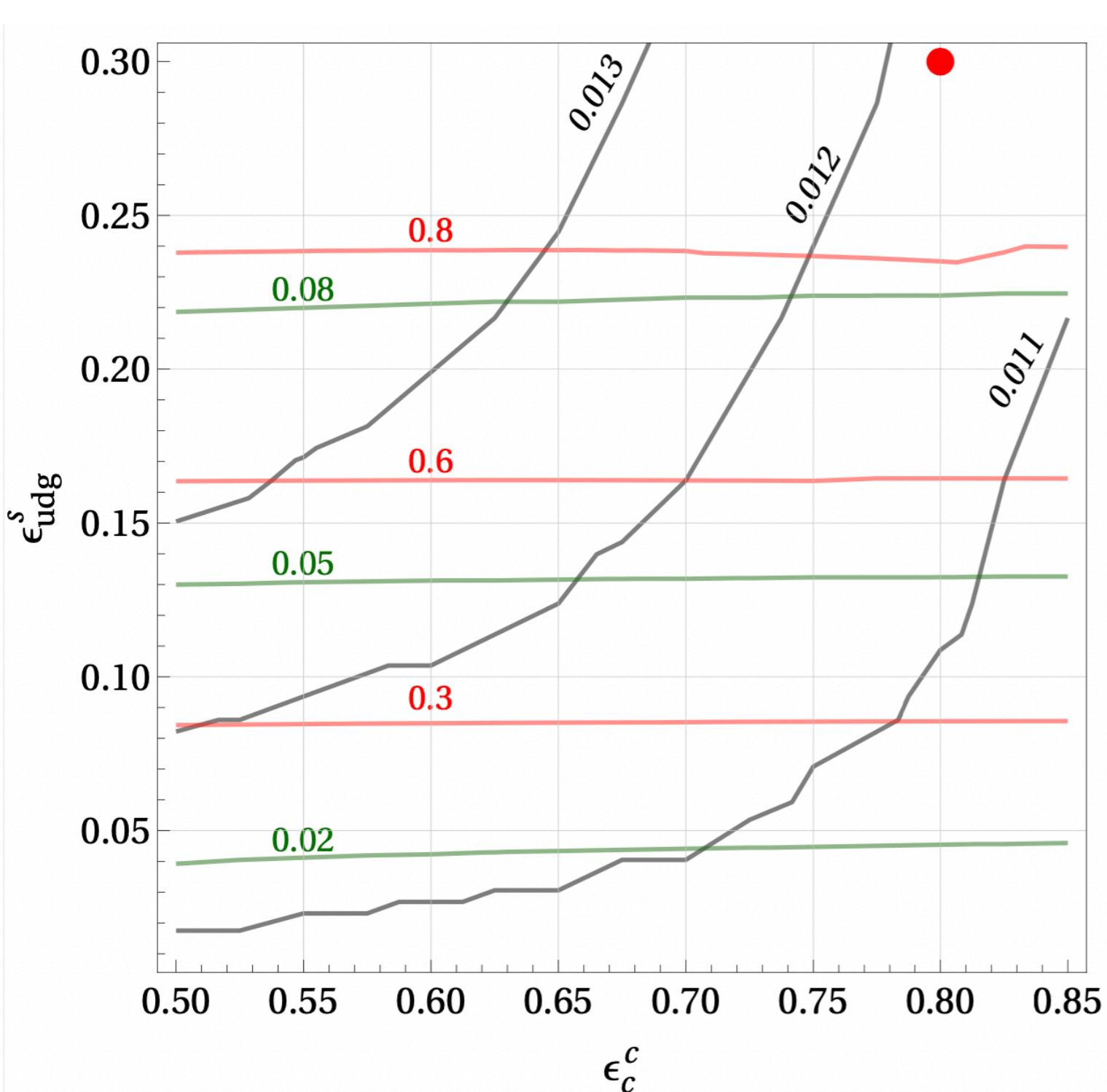
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Results 2: scan parameters



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● FCC-ee Working Point

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Final precision dictated by s-tagger performance

- **Goal:** assess the potential of future lepton colliders to measure CKM elements
- **Ingredients:**
 - Clean environment of e^+e^- colliders
 - State-of-the-art and improved flavor taggers
- **Take home messages:**
 - “Lattice-free” determination of V_{cb} and V_{cs} (and others?)
 - Results depend on taggers performances and systematics

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